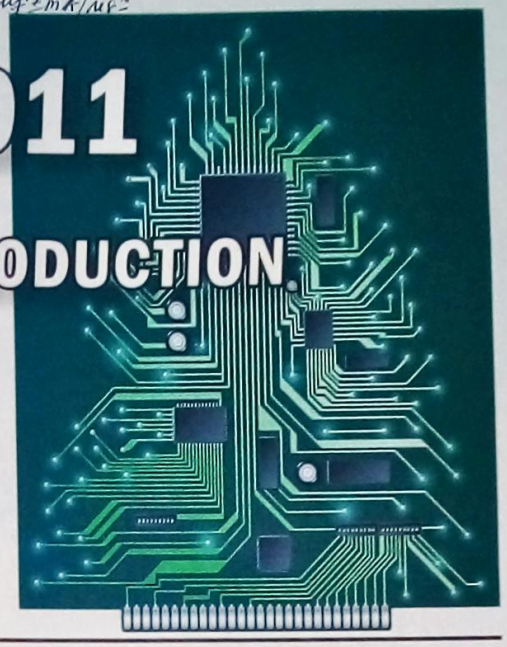

TEACH-IN 2011

A BROAD-BASED INTRODUCTION TO ELECTRONICS

Part 9: Digital-to-Analogue and Analogue-to-Digital Conversion

By Mike and Richard Tooley

Our Teach-In series is designed to provide you with a broad-based introduction to electronics. We have attempted to provide coverage of three of the most important electronics units that are currently studied in many schools and colleges in the UK. These include Edexcel BTEC Level 2 awards, as well as electronics units of the new Diploma in Engineering (also at Level 2). The series will also provide the more experienced reader with an opportunity to 'brush up' on specific topics with which he or she may be less familiar.

Each part of our Teach-In series is organised under five main headings; Learn, Check, Build, Investigate and Amaze. Learn will teach you the theory, Check will help you to check your understanding, and Build will give you an opportunity to build and test simple electronic circuits. Investigate will provide you with a challenge which will allow you to further extend your learning, and finally, Amaze will show you the 'wow factor'!

Learn

IN THIS instalment of *Teach-In 2011*, we introduce some of the combined applications of analogue and digital circuits in the real world. We look at digital-to-analogue and analogue-to-digital converters (DAC, ADC). In *Learn* we explore the circuits and techniques used in DAC and ADC. *Investigate* extends this further with a look at a popular DAC, which is available from several semiconductor manufacturers.

Build looks at some further applications of digital circuits using both combinational and sequential logic techniques. Finally, in ***Amaze*** we look at the way that very large numbers are handled in digital systems.

Signals in the real world exist in analogue (*on/off*) and analogue (*variable*) forms, digital computer systems need to be able to accept and generate both types of signal as inputs and outputs respectively. Because of this, there is a need for devices that can convert signals in analogue form to their equivalent in digital form, and vice versa.

This chapter introduces digital-to-analogue and analogue-to-digital conversion. We shall begin by looking at the essential characteristics of analogue and digital signals and the principle of *quantisation*.

In order to represent an analogue signal using digital codes, it is necessary to approximate (or quantise) the signal into a set of discrete voltage levels, as shown in Fig.9.1 The sixteen quantisation levels for a simple analogue-to-digital converter using a four-bit binary code are shown in Fig.9.2. Note that, in order to accommodate analogue signals that have both positive and negative polarity we have used the two's complement representation to indicate negative voltage levels.

Thus, any voltage represented by a digital code in which the MSB (most significant bit) is logic 1 will be negative. Fig.9.3 shows how a typical analogue signal would be quantised

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Learn

Quantisation

Because signals in the real world exist in both digital (*on/off*) and analogue (*continuously variable*) forms, digital and computer systems need to be able to accept and generate both types of signal as inputs and outputs respectively. Because of this, there is a need for devices that can convert signals in analogue form to their equivalent in digital form, and vice versa.

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Continue to pass the cable through the other three outside holes, then the next across, and so on until the coil is complete. As you go, keep the turns of the coil nice and taut but not so taut as to pull the timber out of the 'X' shape.

When completed, tie a single-loop knot in the last hole so that it keeps the wire loops taut. Again, leave yourself 200mm or so of cable underneath where the PC board will mount, and then cut the remainder off. Hang onto that – you'll need it shortly for the downlink!

Parts List – Active Loop Antenna

*1 PC board, code 813 (Ant Loop) 31mm × 94mm
*1 PC board, code 814 (Rad Loop) 58mm × 48mm
1 Weatherproof plastic box (eg Oatley HB4)
1 30 × 54 × 83mm plastic box
1 8-pin IC socket
* Available from the *EPE PCB Service*

Semiconductors
1 BA4560 dual op amp (IC1)
1 78L08 or 78L10 voltage regulator (REG1)
*2 KDV149 varicap diodes (D1, D2)

Capacitors
3 100µF 16V electrolytic
5 15nF disc ceramic

Resistors (0.25W 5%)
1 470kΩ (code yellow purple yellow gold)
2 220kΩ (code red red yellow gold)
2 47kΩ (code yellow purple orange gold)
2 56Ω (code green blue black gold)
1 47kΩ linear potentiometer (and knob to suit)

Miscellaneous (not included in Oatley Electronics kit)
Timber, screws and mounting hardware as required
40m of 4-wire telephone cable or equivalent

PC board construction

The printed circuit boards component layouts and interwiring are shown in Fig.3. These two boards (together with two Varicaps) are available as a pair from the *EPE PCB Service*, codes 813 (Ant Loop) and 814 (Radio Coupling).

It doesn't matter which board you start with – both are quite simple and should only take an hour or so to complete. On the loop antenna board, the only polarised components are the amplifier IC, the electrolytic capacitor alongside it and the varicap diodes.

Start by installing the smallest components – the resistors and non-polarised capacitors, then install the semiconductors and the electrolytic capacitor. Don't worry about the loop or downlink wiring at the moment.

On the power supply board, three of the five components are polarised, so make sure you get them in the right way. The potentiometer will only go in one way (otherwise the shaft points inwards).

Loop and downlink wiring

In the prototype, 4-wire telephone cable was used because this happened to be on hand – even though the loop antenna does not use the four individual wires (however, the downlink does).

Therefore you could just as easily use single-conductor wire for the loop if you wished. Note that telephone cable is quite a lot tougher than single wire and so offers some protection from, for example, birds sitting on it or even pecking at it!

If you use telephone cable for the loop antenna wiring, simply connect all four wires in parallel as you solder them to the PC board. The same applies for the output loop – the one which goes around your radio. The wires can be twisted together to make this easier. Note that all connecting wires solder to the pads on the underside of the PC board.

You might be wondering why each single wire of the telephone cable was not connected in series with its mate and terminated as such on the PC board. Wouldn't this create a significantly greater inductance (ie, four times greater)?

Oatley Electronics originally had exactly the same idea. Unfortunately, when they tried it out, they found that the capacitance of the closely-spaced wires within the cable started to create its own problems.

They found that by paralleling all four wires in the cable, this problem was eliminated. More importantly, they found that the overall performance of the antenna was better!

In the downlink, all four wires in the telephone cable are used independently and are connected to the points A, B, C and D on the PC boards.

With coloured wiring in the cable (black, red, blue and white), it's not easy to get it wrong!

This downlink wiring can be quite long – the prototype had 20m between the two PC boards, and there didn't appear to be any loss of signal compared to a 5m separation. If you need more distance, give it a go – you have nothing (except signal) to lose.

In use

If possible, make a complete turn around the radio receiver with the output loop (remember, the radio *must* have a ferrite rod for this antenna to work). How do you know if it has a ferrite rod antenna? If you can turn it on and it works without anything connected, it's a pretty fair bet that it has one. Virtually all small AM radios have a ferrite rod antenna inside.

Tune the radio to the weak station you want to listen to. Now adjust the potentiometer slowly – at one point, you should find a significant increase in the level of that station (or a decrease in any other stations that are interfering with it).

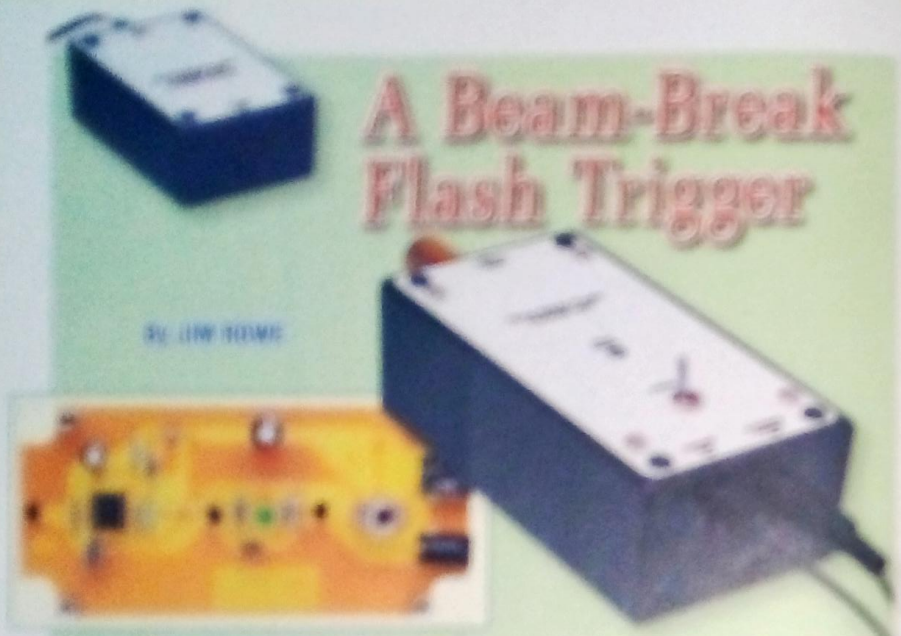
Also, recall what we said before about the antenna being able to turn so that it faces the wanted station – by facing, we mean broadside on, or if you take a line across the X frame the wanted station should be perpendicular to that line.

The antenna will work equally well from both sides. However, if you turn the antenna through 90°, you should find that its performances decreases significantly. Conversely, any other stations that are now broadside-on will be much better. ***EPE***

WHERE FROM, HOW MUCH?

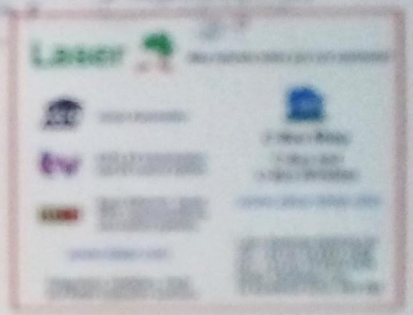
This project was designed by Oatley Electronics who retain the copyright. A kit for this project (K256), which includes both PC boards, on-board components and cases (as listed above) is available from Oatley Electronics, for about £15. The kit does not include the 4-wire telephone cable nor any timber or mounting hardware. Contact Oatley Electronics via their website: www.oatleyelectronics.com

A Beam-Break Flash Trigger



By JIM SOWC

Here's an easy-to-build accessory for the Time Delay Photoflash Trigger described in our February 2011 issue. It triggers the flash unit and your photoflash in response to an object interrupting an invisible beam of infrared light. Alternatively, it can be used on its own to directly trigger a photoflash.



Ingenuity Unlimited

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We pay between £10 and £50 for all material published, depending on length and technical merit. We're looking for novel applications and circuit designs, not simply mechanical, electrical or software ideas. Ideas must be the reader's own work and **must not have been published or submitted for publication elsewhere**.

The circuits shown have NOT been proven by us. **Ingenuity Unlimited** is open to ALL abilities, but items for consideration in this column should be typed or word-processed, with a brief circuit description (between 100 and 500 words maximum) and include a full circuit diagram showing all component values. **Please draw all circuit schematics as clearly as possible**. Send your circuit ideas to: Ingenuity Unlimited, Wimborne Publishing Ltd., 113 Lynwood Drive, Merley, Wimborne, Dorset BH21 1UU. Email: editorial@epemag.wimborne.co.uk.

Your ideas could earn you some cash and a prize!

PCB Track Probing unit – *On track*

I RECENTLY purchased from *EPE* the Version 3 PICmicro MCU development board. Unfortunately, this unit comes without any instructions, circuit diagram or even block diagram. As I wish to use this versatile looking piece of equipment to develop PIC circuits of my own design, I needed to ascertain where connectors and plugs and sockets were connected in the circuit.

I have used the idea I am about to describe many times before in lash-up form, but felt that I ought to make this one as a completed unit, calibrated and mounted in a convenient box and having suitable probes. I then realised that it could be of interest to other readers of *EPE*, hence this letter/IU.

On track

The requirement was to be able to trace printed circuit tracks between components, IC pins, and sockets, even while components populate the PCB, but without power being connected. This probing should not cause any junctions that are connected between the probes to turn 'on' and should show unambiguous connections, while possibly being able to measure track resistance at the same time.

The finished circuit will allow the measurement of resistance, up to two hundred ohms in my case. This figure could be changed if required, but for my intended use this is adequate. If a track reading is below the calibrated set point on the dial, an audible sound is heard.

Circuit details

I decided to use a low voltage of about 0.3V to power the probes, and a variable trip point on a comparator to sense the connections and its resistance between pins and tracks. The low voltage is derived by using a resistor chain from both the positive supply and also the negative supply (a single 9V battery) with a 1N4002 'dropper' diode, as may be observed from the circuit diagram Fig.1.

As the circuit around the 'dropper' diode is a DC Wheatstone bridge, the trip point could be used to infer low values of resistance of track. The bridge detector is the high gain (open loop) differential circuit, the output of which triggers an audible warning output stage.

The circuit is powered with a single 9V battery. The low probe voltage is derived from the voltage drop across D1, a 1N4002 silicon rectifier. It is tapped down using a couple of 1.5kΩ resistors in the upper arms, with a 250Ω variable resistor (pot.) shunting one of the arms as shown. The probes connect across the other lower arm. These resistors form the Wheatstone bridge circuit, with the probe as the unknown value.

When the 'test' PCB is probed, if track exists between the probe points, then the voltage across the probe falls, depending upon the resistance of the track. This drop in voltage is sensed by a comparator (IC1a) with an adjustable reference voltage, also derived from the potted down voltage from the D1.

The output from the comparator turns on an oscillator (IC1b) driving a piezo sounder. I use an audible warning instead of an LED, as this means that I do not have to switch my eyes back and forth while probing. By adjusting the trip point, an indication may be made of the resistance of a track, or the classic Wheatstone bridge method. In normal use, one leg is the indicator [illegible] but [illegible] go-no-go' [illegible]ation, [illegible] at the [illegible]sistance

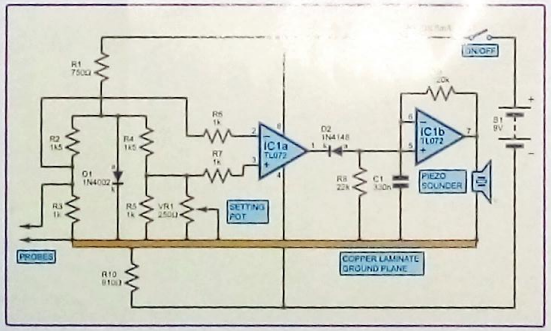


Fig 1. Circuit diagram for the PCB track probe

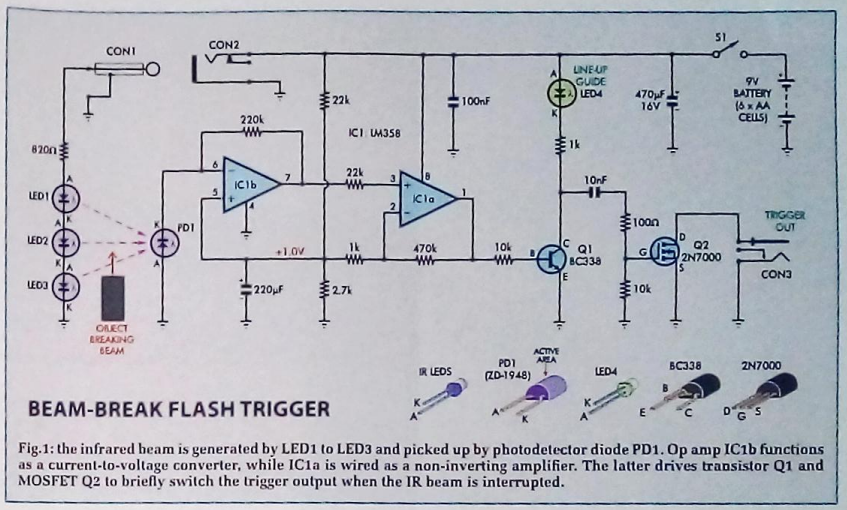


Fig.1: the infrared beam is generated by LED1 to LED3 and picked up by photodetector diode PD1. Op amp IC1b functions as a current-to-voltage converter, while IC1a is wired as a non-inverting amplifier. The latter drives transistor Q1 and MOSFET Q2 to briefly switch the trigger output when the IR beam is interrupted.

Both parts of the project run from a 9V battery fitted inside the Detector unit's box. The total current drain is about 15mA, which means that the battery should be either a set of six AA (1.5V) alkaline cells or a single high-energy 9V lithium battery. A standard 9V zinc-carbon or alkaline battery is not up to the job, as its life would be too short.

Circuit details

The complete circuit diagram for the *Beam-Break Flash Trigger* is shown in Fig.1. There's really not a great deal in either part of the circuit. In fact, the IR Source unit is nothing more than three IR LEDs connected in series, plus an 820Ω series resistor. This resistor limits the current from the 9V supply (and thus the current through the IR LEDs) to about 7.5mA.

Power is derived from the battery in the Detector unit via a cable fitted with a 3.5mm jack plug (CON1). This mates with CON2 on the detector unit.

In the Detector unit, the IR beam from the Source unit normally falls on PD1, an IR photodetector diode. This photodetector is connected between ground and the inverting input (pin 6) of op amp IC1b (an LM358).

Op amp IC1b is connected as a current-to-voltage converter. Its pin 7 output sits somewhere between +1.7V and +4.0V when the IR beam is present, but rests close to +1.0V when no IR light is falling on PD1. This 'dark' output voltage of +1.0V is basically set by the voltage divider formed by the 22kΩ and 2.7kΩ resistors, with the 220µF capacitor providing filtering. This is used to directly bias pin 5 of IC1b and to bias pin 2 of IC1a via a 1kΩ resistor.

The output at pin 7 of IC1b is fed to the non-inverting input (pin 3) of IC1a, which is configured as a non-inverting amplifier with a voltage gain of 471. Because of this very high gain, IC1a acts very much like a comparator. Its pin 1 output sits at over +8V when the IR beam is present, but falls to 0V when there is no IR light falling on PD1 (ie, the IR beam is interrupted).

IC1a's output in turn drives the base of transistor Q1 via a 10kΩ resistor. As a result, Q1 is turned on or off depending on whether the IR beam is present or not. When the IR beam is present, Q1 is on and when the beam is interrupted, Q1 turns off.

LED4 and its series 1kΩ resistor form the collector load of Q1. This means that LED4 lights when Q1 is on and turns off when Q1 is off. This allows LED4 to be used as a guide when lining-up the Source's IR beam with PD1, as described previously.

Switching the trigger output

Because Q1 is switched on when the IR beam falls on PD1, its collector voltage is normally held down to about 0.4V. However, if the beam is interrupted, Q1 turns off and its collector voltage rises to nearly +9V.

This sudden voltage change is used to switch on Q2, a 2N7000 MOSFET, which is used as an output switch across triggering output CON3. As shown, a 10nF coupling capacitor and Q2's 10kΩ gate resistor form a simple differentiating circuit. This results in Q2 being switched on only briefly when Q1's collector voltage rises when the beam is interrupted. The 100Ω resistor in series with the coupling capacitor is there to suppress any possible oscillation during switch-on or switch-off.

That's about it, apart from power switch S1 and the 470µF and 100nF capacitors, which decouple the supply rail voltage to keep it constant. The current drain of the detector circuit varies between about 7.5mA when the IR beam is present and 1.5mA when it is interrupted, so the total battery drain for both sections varies between 15mA (beam present) and 9mA (beam interrupted).

Parts List

IR Source Unit

*1 PC board, code 808, size 57mm × 26mm
1 UB5-size box, 82mm × 53mm × 31mm
4 6mm long untapped spacers
4 M3 × 12mm screws, countersink head
4 M3 hex nuts
1 nylon cable tie, 75mm long
1 2m length of figure-8 cable
1 3.5mm mono jack plug, cable type (CON1)
3 5mm IR LEDs (LED1 to LED3)
1 820Ω resistor

Detector Unit

*1 PC board, code 809, size 122mm × 58mm
1 UB3-size box, 129mm × 68mm × 44mm
1 SPDT mini toggle switch (S1)
1 PC-mount 3.5mm stereo jack socket (CON2)
1 PC-mount 2.5mm concentric power plug (CON3)
4 M3 × 15mm tapped spacers
8 M3 × 6mm machine screws, pan head
2 1mm PC board terminal pins
1 9V battery clip lead
1 8-pin DIL IC socket
1 300mm length of 12mm to 15mm diameter black PVC conduit or brass tubing
1 piece of IR-transparent red film, approx. 16mm square
1 9V battery snap connector OR 1 x 4-way AA cell holder plus 1 x 2-way AA cell holder

Semiconductors

1 LM358 dual op amp (IC1)
1 BC338 *NPN* transistor (Q1)
1 2N7000 *N-channel* MOSFET (Q2)
1 IR photodetector (PD1) (Jaycar ZD-1948 or similar)
1 5mm green LED (LED4)

Capacitors

1 470µF 16V radial elect.
1 220µF 16V radial elect.
1 100nF metallised polyester
1 10nF metallised polyester

Resistors (0.25W 1%)

1 470kΩ	1 2.7kΩ
1 220kΩ	2 1kΩ
2 22kΩ	1 100Ω
2 10kΩ	

* Available as a pair from the *EPE PCB Service*

The IR Source board carries the three infrared LEDs (LEDs1-3) plus an 820Ω current-limiting resistor. It's mounted inside a UB5 case on 6mm untapped spacers and derives its power from the Detector unit.

Construction

You can see from the photos that the two units which make up the Beam-Break Flash Trigger are each housed in a small plastic box. The IR Source circuit is built on a small PC board coded 808 (57mm × 26mm), while the Detector parts are installed on a larger PC board coded 809 (122mm × 58mm). These boards are available as a pair from the *EPE PCB Service*.

Start the assembly by building the IR Source board – see Fig.2. This should take you just a few minutes, since there are only four components to install – the three infrared LEDs and the 820Ω current-limiting resistor.

Be sure to orient the three IR LEDs correctly, as shown in Fig.2. **In addition, these three LEDs must be fitted with their leads bent down by 90°, so they face out of the end of the box when the board is mounted inside.**

In particular, note that the centre LED (LED2) is fitted with its body relatively low down near the board, while the two outer LEDs are fitted higher and with their leads bent inwards towards LED2. This is done so that they form a triangular group, to provide a relatively compact beam source (see photo above).

Once these parts are in, install the power cable by soldering its leads to the +9V and 0V pads. The cable is then anchored using a small nylon cable tie that passes through the two 3mm holes on either side.

Having completed the board, it can be mounted inside a plastic box on four 6mm untapped spacers, and secured using four 12mm countersunk head screws. As shown in the photos, the LEDs face outwards through a 10mm hole in one end of the box, while the cable exits via a small notch filed in the top at the opposite end. Fig.3 shows where to drill the holes in both.

Finally, complete the Detector unit by attaching the front panel label to the lid. A full-size artwork is shown

Table 1: Resistor Colour Codes

No.	Value	4-Band Code (1%)	5-Band Code (1%)
1	470kΩ	yellow violet yellow brown	yellow violet black orange brown
1	220kΩ	red red yellow brown	red red black orange brown
2	22kΩ	red red orange brown	red red black red brown
2	10kΩ	brown black orange brown	brown black black red brown
1	2.7kΩ	red violet red brown	red violet black brown brown
2	1kΩ	brown black red brown	brown black black brown brown
1	820Ω	grey red brown brown	grey red black black brown
1	100Ω	brown black brown brown	brown black black black brown

. . . and a cheap 'Slim Jim' antenna to make

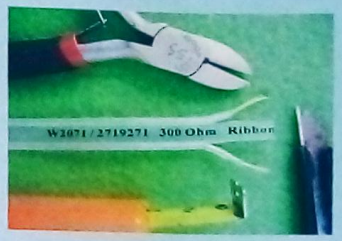
By Stan Swan

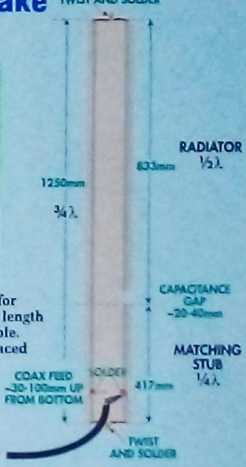
A DIY 'Slim JIM'

One of the most appealing antennas for such work is the so called 'Slim Jim' (an acronym for 'J-type Integrated Match') – invented in 1978 by the late Fred Judd, G2BCX.

Any parallel conductors could be used (some diehards swear by HO-scale model train track!), but such an antenna can be quickly and cheaply made from a length of 300Ω impedance TV ribbon.

This is becoming rather difficult to get, having largely given way to 75Ω coaxial cable (which is, of course, entirely *unsuitable*).





A 'Slim Jim' antenna for 162MHz made from a length of 300Ω TV ribbon cable. This would best be placed inside a length of plastic conduit and mounted outside, as high as possible and away from metal (such as a mast or roof).

Although cheap, this ribbon rapidly deteriorates in the wind and sun if left unprotected, so housing inside a vertically supported plastic conduit (eg, mains conduit) is almost essential for outside use. Plastic conduit will not degrade performance at all.

Considerable variation on the basic design can be tolerated, as aspects such as the gap space, conductor spacing, velocity factor (VF) of the wire and even nearby metallic objects influence performance.

At 162MHz, an open-space wavelength = speed/frequency = $3 \times 10^8 / 1.62 \times 10^8$ = 1850mm. However, slower signals within the TV ribbon decrease this by ~0.9 (known as the velocity factor) giving a working AIS wavelength of 1665mm.

A Slim Jim is ¾-wavelength long (although only the upper half-wave portion receives), so a 1250mm antenna length should suffice. 'Cut and try' experimentation is encouraged – cut slightly longer initially and trim to suit for best performance.

Whilst any TV-grade (ie 75Ω) coax suits Slim Jim connection to the VHF receiver's BNC antenna socket, and use of this grade flexible coax makes a roll-up version feasible. Unless you're making a very long run from antenna to receiver, losses should not be too much of a problem. Of course, if your run is long (ie, greater than, say 10m), go for one of the better (low-loss) cables.

To construct a Slim Jim, simply follow the diagram at top right. You'll need a length of ribbon cable about 1280mm long, to allow the two ends to be stripped and shorted, as shown.

The wires at each end of the cable are bared, twisted together and soldered (don't ignore the last part, especially if you are going to erect the antenna outside). In fact, a short length (30mm or so?) of heatshrink tubing over each end will further protect the copper wire from corrosion.

The exact position for the coax feed connection is not all that important for a receiving antenna – between 30 and 100mm up from the bottom is the range. The centre wire of the coax is soldered to the ¾ wavelength side (don't cut the wire, just remove the insulation) while the braid connects to the matching stub opposite the centre wire connection point.

The capacitance gap, on the 'earthy' side only, can be anywhere from about 20mm to 40mm. Don't simply cut the cable; the short length of wire needs to be removed.

Apart from putting it inside a suitable length of conduit (say 1.3m) with a plug on the top end (the bottom end could be filled with silicone sealant to stop insects and spiders calling the Slim Jim home), your antenna is now complete and ready for use.

Slim Jim low angle performance is legendary, as the design best handles signals received near parallel to the ground – forget it for near-overhead aircraft and satellites!

Unless you're tracking flying boats (or live on a hilltop), vessels are naturally going to be near-horizontal anyway. Slim Jim AIS reception out to 20nm (~30km) could be expected when the antenna is well elevated, perhaps by being hoisted up a tree (inside a conduit) with a nylon line.

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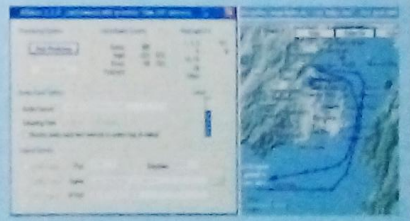

Stan, monitoring at Eastbourne (green symbol) tracks two vessels using VHF radio AIS into and out of Wellington harbour. This gives a good idea of the type of performance to expect using the modified scanner and Slim Jim antenna described here and AISMon software running on your PC.